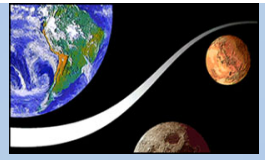

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STARDUST LESSONS IN LEARNING:

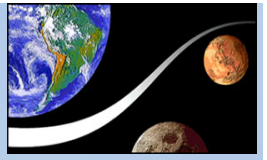
Why the Benefit to the CEV Program Could be Greater

Presented to PM Challenge 2009 by:
Karen M. McNamara
Astromaterials Research and Exploration Science
Johnson Space Center

Joseph Vellinga
Lockheed Martin Space Systems

Dean Kontinos
Ames Research Laboratory

And the Stardust Team



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Presentation Outline

- Introduction to the Stardust Mission
- Sample Return Capsule and Heatshield
- Connections to Orion/CEV
- Missed Opportunities: What & Why?
- Planning for Learning
- Lessons from Stardust Recovery
- Re-thinking Technology Development: **Lessons IN Learning**

Comet Sample Return

Discovery Class Mission

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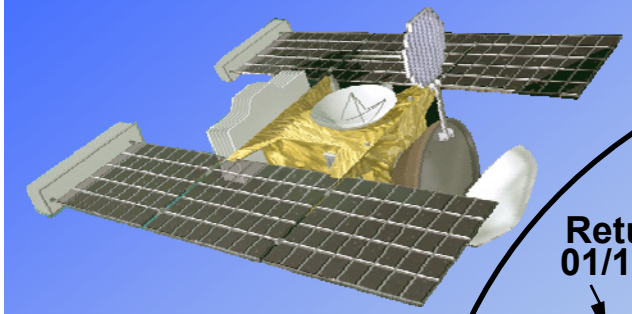
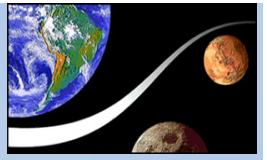
Launch February 7, 1999

Return January 15, 2006

STARDUST
NASA's COMET SAMPLE RETURN MISSION

Spacecraft Trajectory





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Comet Sample Return

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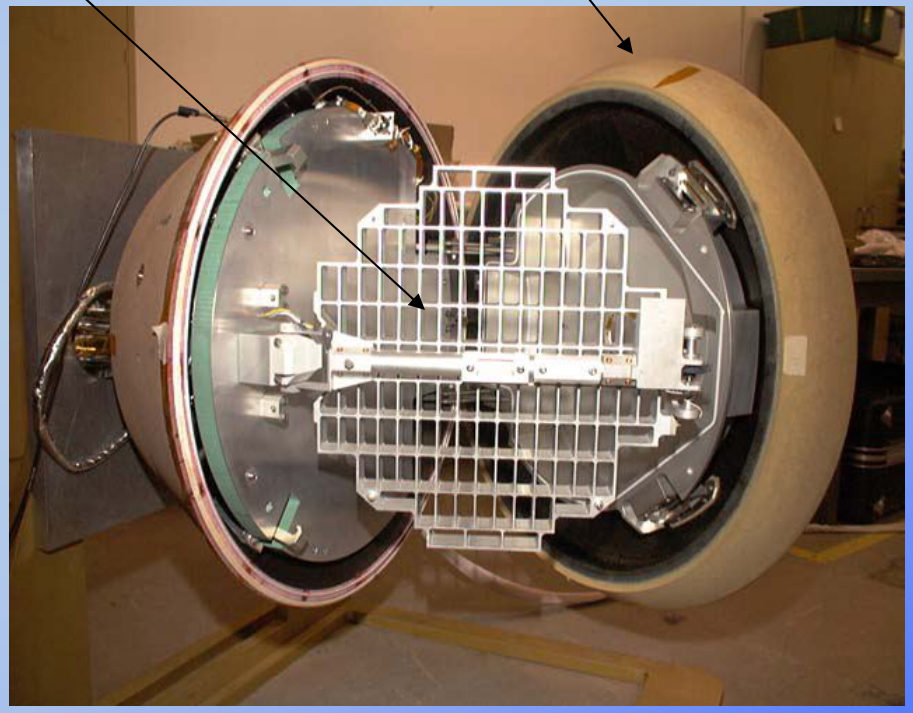
Heatshield

Spacecraft Ready for shipment to Cape

Aerogel Collector Grid

Heatshield



Open EM Science Canister w/aerogel

STARDUST
NASA's COMET SAMPLE RETURN MISSION

Encounter at Wild-2 & Return to Earth

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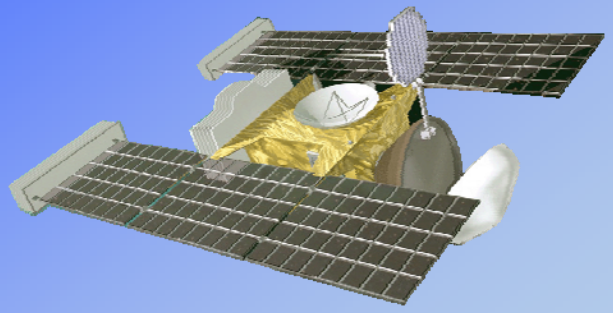

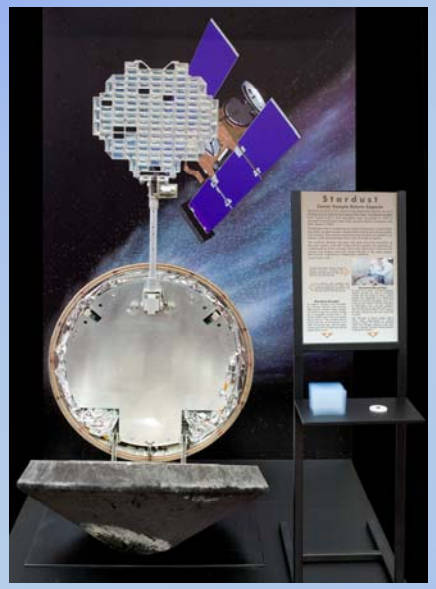

Mission Success

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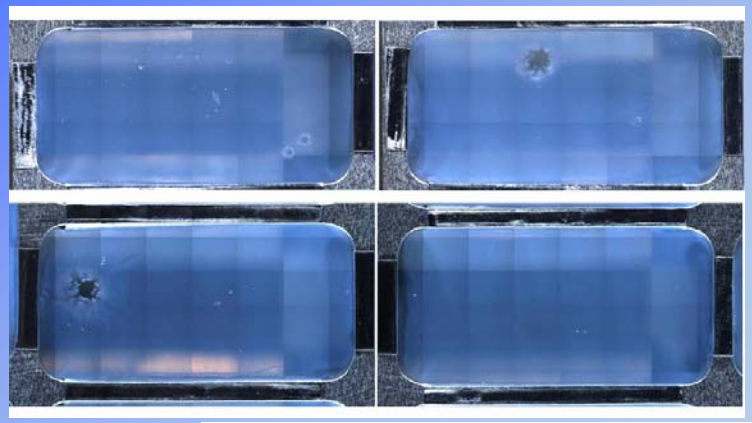
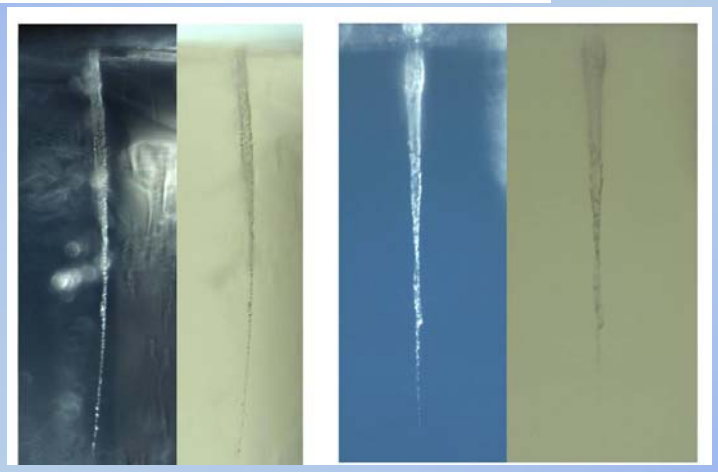
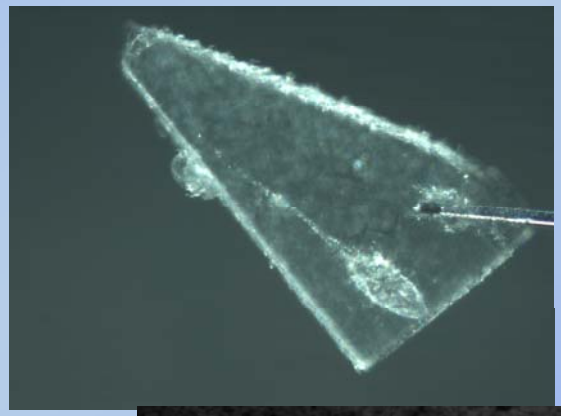
Aerogel Cells with Impacts

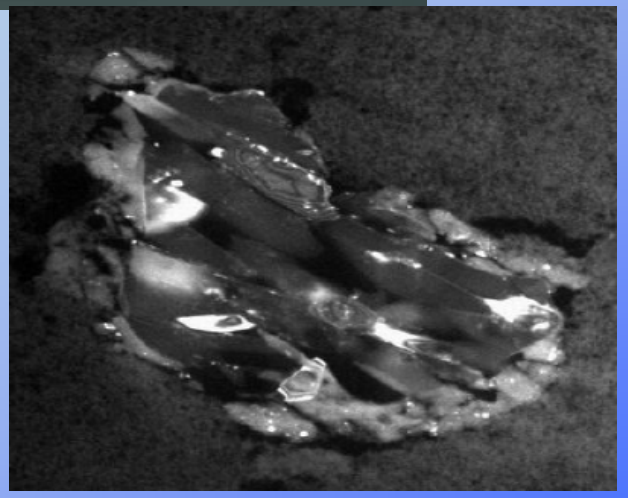




Particle Tracks in Aerogel

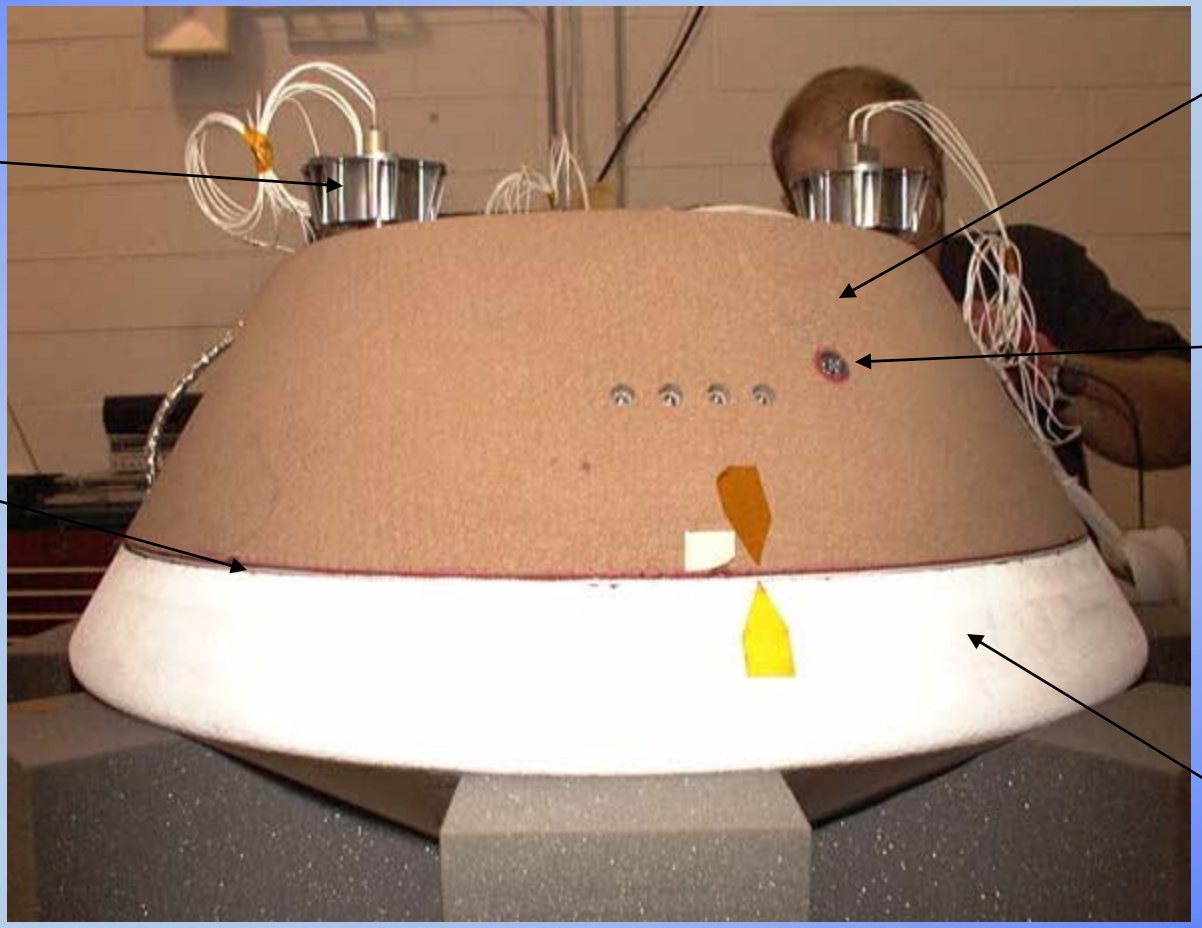
Keystone Sample with 1 particle track





Olivine Particle

Sample Return Capsule



Separation Bolts (3)

Seal Plane Of Sample Canister & Heatshield To Backshell

Backshell, Super Light Ablator (SLA) 561

Air Vents (2) for Launch Depress, Return Repress

Heatshield (PICA)

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STARDUST
NASA's COMET SAMPLE RETURN MISSION

Fasted ReEntry of Any Man-made Object

High heat flux > 1100 W/cm^2

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STARDUST
NASA's COMET SAMPLE RETURN MISSION

PICA Heatshield

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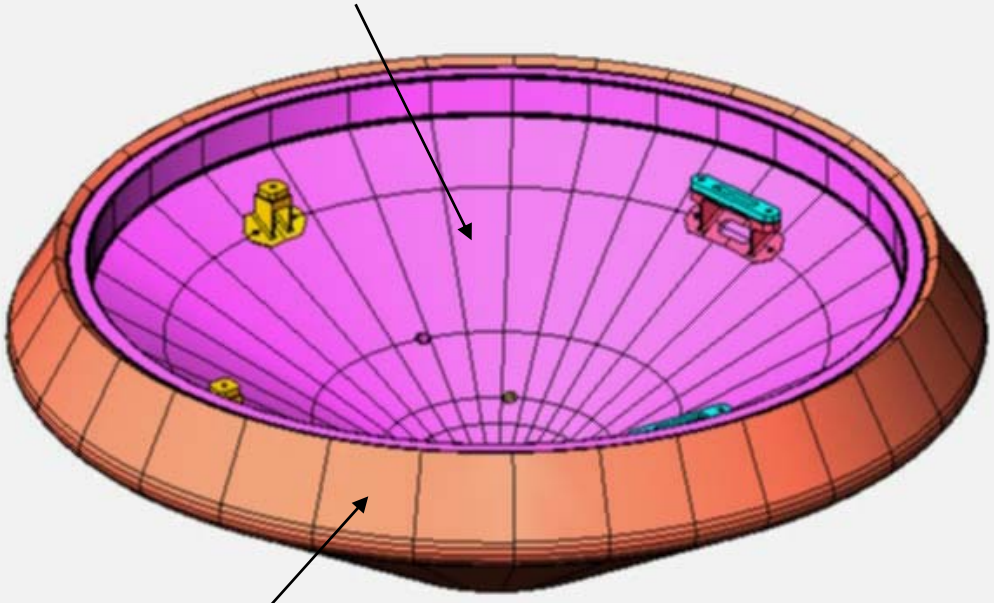
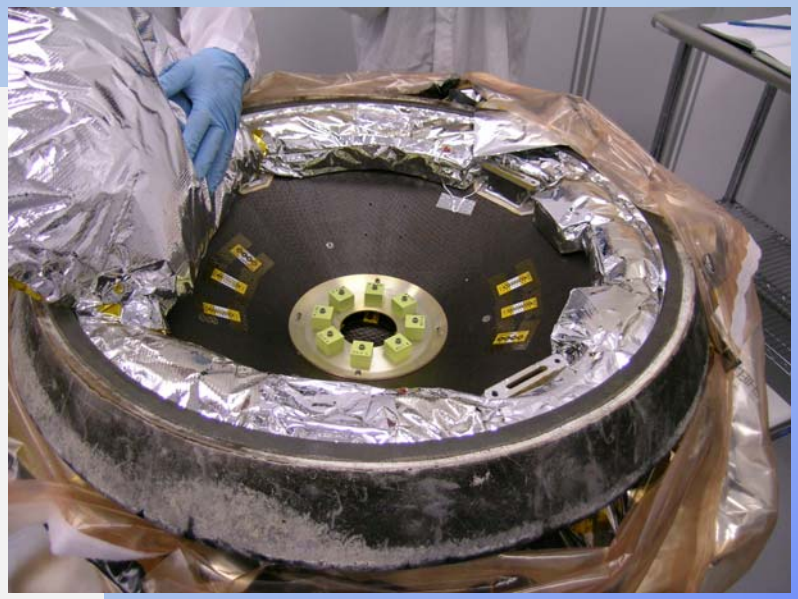
Composite Structure





What is PICA?

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Phenolic Impregnated Carbon Ablator

Low Density (≤0.17 g/cm^3) Carbon Fiber Matrix

Impregnated w/phenolic resin & cured to final density ≤0.27 g/cm^3

PICA before ablation

PICA after ablation

PICA Shell is shown bonded to composite support structure. The Stardust heatshield was one solid PICA casting.

Connections to Orion

What could we learn?

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Similarities

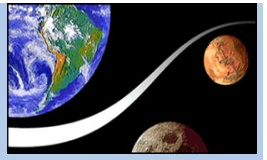
Direct Earth Entry
High Velocity/Heating
Proposed PICA Heatshield

Potential Data

Total Recession
Spatially Resolved Recession
Local heating (chemistry)
Turbulence: Edge Effects

Important Considerations

Stardust is only PICA flight case
TRL 4 to flight in 2 years
Single piece
23 PICA castings required for 2 on-spec



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Missing Pre-flight Data

In hindsight what would we measure?

No Effect on Design

Detail Photodocumentation

Initial PICA Thickness (Spatially Resolved)

Imaging and Surface Characterization

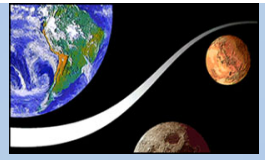
Pre/Post Integration w/Composite

Witness coupons

Design Impact

TPS Instrumentation

(Note: Passive temperature strips were installed.)



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Why didn't we do it?

Pre-Flight Measurements

Beyond Mission Scope

No Funding

Unfamiliar Mission Scenario

Not in Our Culture

Planning: Nobody's "Job"

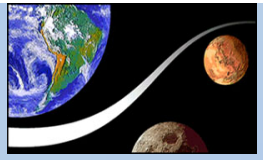
TPS Instrumentation

Deliberate Project Decision

Design Impact: Risk, Cost, Schedule

Goal Identified Extremely Late in Program

PICA Highest Mission Risk: TRL 4 to flight in 2 years



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Post-flight Measurements

What did we do?

Measurements After Return

Visual Observations; Photodocumentation

Maximum T: Passive T-strips

Laser Surface Mapping (recession)

Compare to Pre-flight Drawing (recession)

UV Spectroscopy

Solar Absorptivity/ Emmisivity

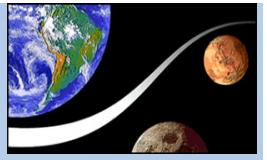
IR Spectral Reflectance

Organic & Inorganic Surface Sample Chemistry

Core Sampling (recession)

CT Scanning (recession)

LASER Surface Mapping



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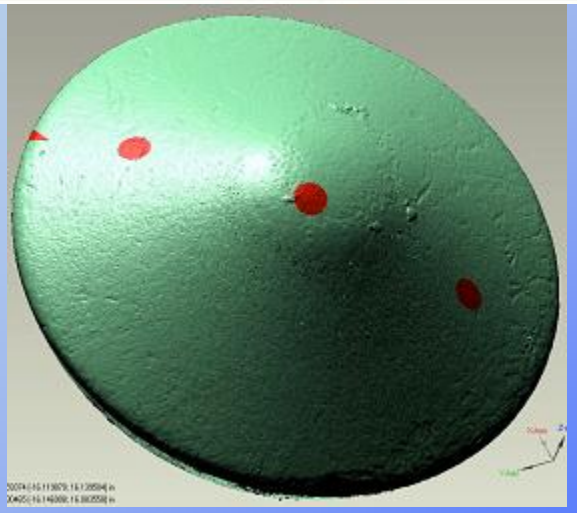
Laboratory Set-up:
Non-Contact



Laser Maps showing detailed surface features
And core sampling locations

Flight Drawing Template

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Based on Drawings – Not Actual

Measurement using the Unaided Eye

"Essentially" Non-Contact

STARDUST
NASA's COMET SAMPLE RETURN MISSION

Extracting Cores

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2” diameter core samples were extracted from the nose and flank of the heatshield

Physical Handling/Deterioration
Mechanical Abrasion and Warping

CT Scanning

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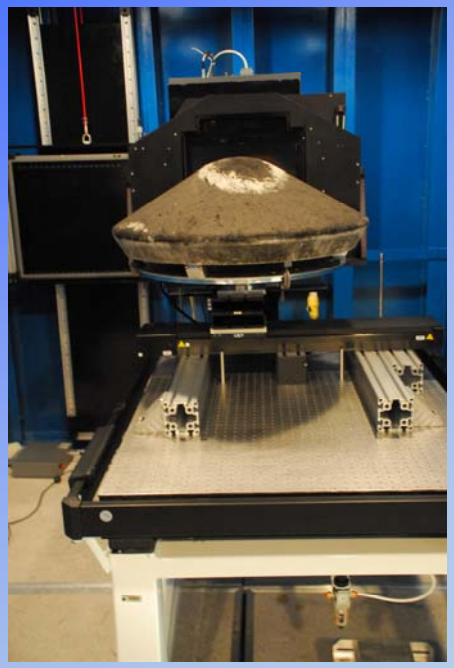
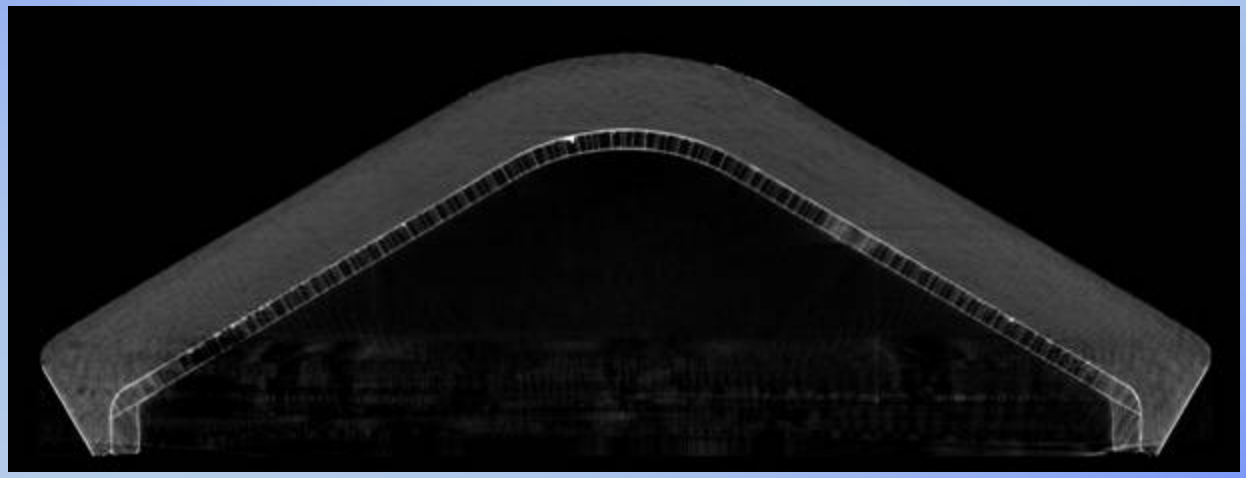
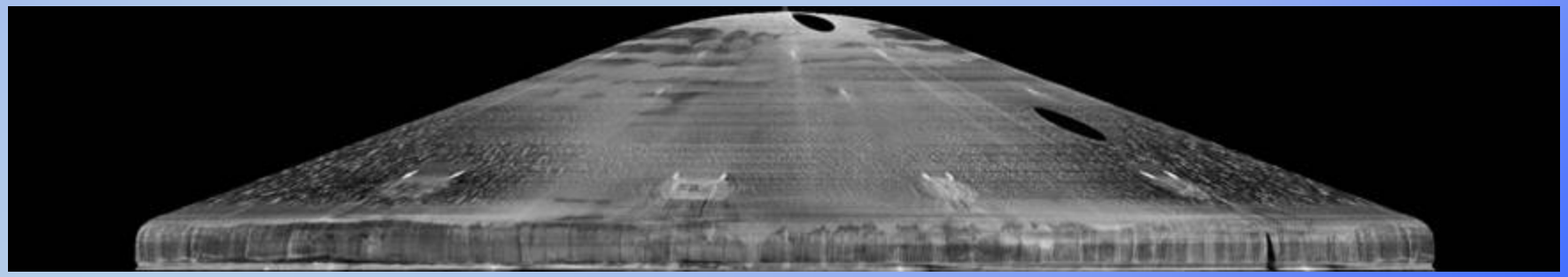


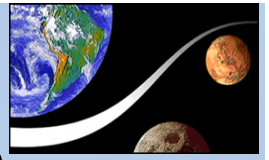
Better than 300mm resolution
Non-Contact



Cross-section showing thickness, bond layer, density gradient



Bond line shell showing gaps between PICA and Composite structure



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But can we Calculate Recession?

NO!

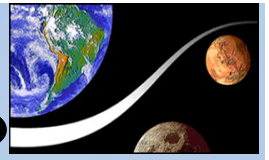
RECESSION = ~~BEFORE~~ - AFTER

No analytical measurement can make up for planning!

We can learn a lot from Stardust.
But we could have learned more.

HOW?? By Planning for Learning!

How Could we have learned more?



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Design Phase: What do you wish you knew? What is limiting your capability? How about on your last project?

How would you find out? A real mission is the ultimate test program. Let one mission build on another.

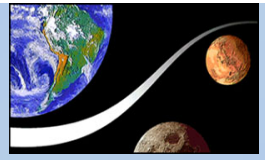
Is there an indirect way to obtain the data? (witness coupons...)

Do your operations interfere with your observations? Do they have to? Are there no cost alternatives that would add value to learning?

Document the Details: Cameras are cheap!

This needs to be someone's job or it doesn't happen

Planning for Learning!



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Lesson in Learning

We are a "Lesson Learned" culture

Lessons Learned is "reactive."

Planning for Learning is "Proactive."

Recovery Processing

Be Prepared for the Unexpected

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Heatshields bounce!

And paint doesn't always stick!
(Or burn-off on re-entry)

And roll!

Recovery Processing

Plan to Learn in Every Phase of the Mission

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Heatshield don't have handles

That first step was a doosey

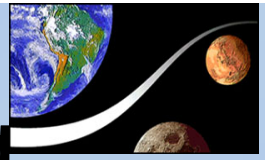
OUCH!

Did anyone bring the can opener?

That was just a joke – the lid's tied on anyway!

STARDUST
NASA's COMET SAMPLE RETURN MISSION

Impacts of Recovery Handling



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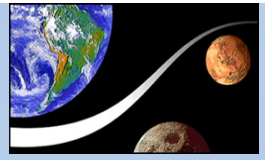
These operations actually effect our ability to understand the post-entry condition of the heatshield. Could we have reduced the effects if we had Planned for Learning?

Can you imagine if we had landed in water!?!



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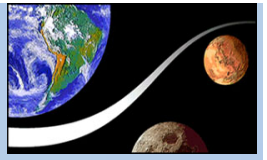
Lessons IN Learning

Re-thinking Technology Development

- Plan for learning agency-wide
- Look across directorates, disciplines and budgets
- Support, even initiate Planning for Learning from outside project/program
- Accompanied by authority, budget schedule accommodation...etc.
- If it is not done in advance – no mission can accommodate
- Needs to be identified in proposal stage/planning stage – Before requirements development!
- Dedicated part of technology development program – this needs to be someone's job!



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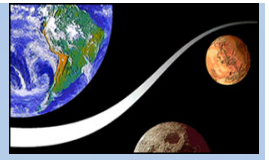
Take-Home Message

Lessons Learned is "reactive."

Planning for Learning is "Proactive."



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Thank you for attention!

Discussion?